



---

---

# Shared Aperture Diffractive Optical Elements (ShADOE)

An ESTO ACT Program

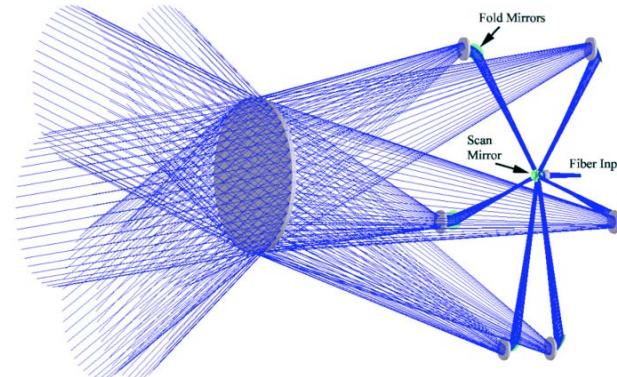
Bruce Gentry (*NASA*), Principal Investigator

Geary Schwemmer (*SESI*), Anthony Martino (*NASA*)

Brent Bos (*NASA*), Co-Investigators

Other Team Members

Caner Cooperrider, Cathy Marx





# Outline

---

---

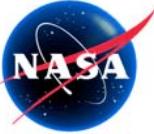
- Objectives
- Approach
- Prior Art
- SHADOE Technology
- Mission Concept
- Wind Lidar System Requirements
- SHADOE Telescope Requirements
- Progress
- Risks
- Risk Mitigation
- Plans
- Summary



# Objectives

---

- Enable atmospheric Doppler and surface mapping *scanning* lidar applications from space by minimizing telescope weight & torque
- Leverage current and past investments in HOE technology by GSFC SBIR, R&TD and IRAD programs



# Approach

---

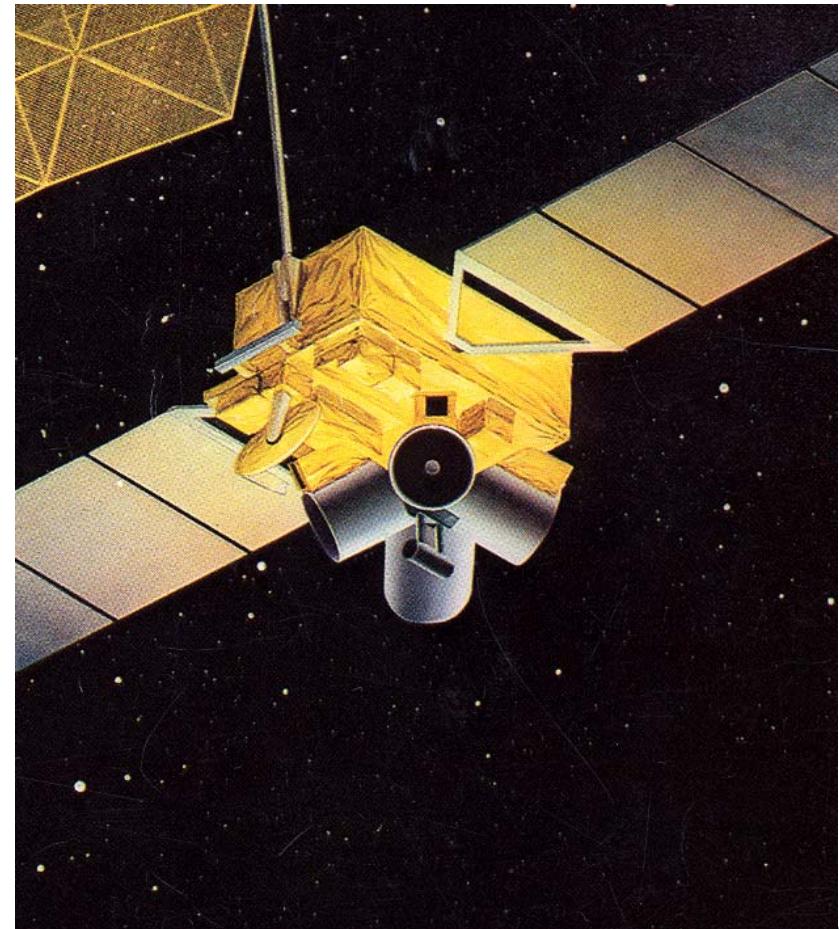
---

- Develop *angle-multiplexed* diffraction limited holographic or diffractive optical elements at 2054 nm wavelength and near diffraction limited at 355 nm
- Breadboard & demonstrate a multi-wavelength ShADoE telescope suitable for use with single and dual-wavelength lidars



# Competing Technologies (prior art)

- Conventional telescope w/ rotating mount
- Multiple telescopes
- Scanning flat mirror
- Rotating wedge prism
- Rotating Fresnel prism
- Rotating HOE
- Multiplexed HOE / SHADOE

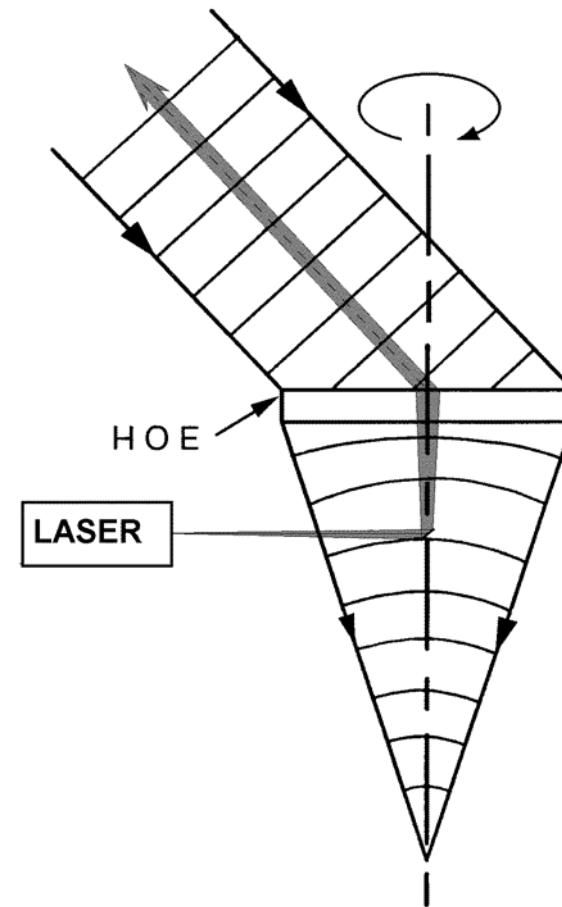




# Holographic Optical Element Scanning Telescope



Holographic Airborne Rotating Lidar  
Instrument Experiment (HARLIE)





# HOE Properties

---

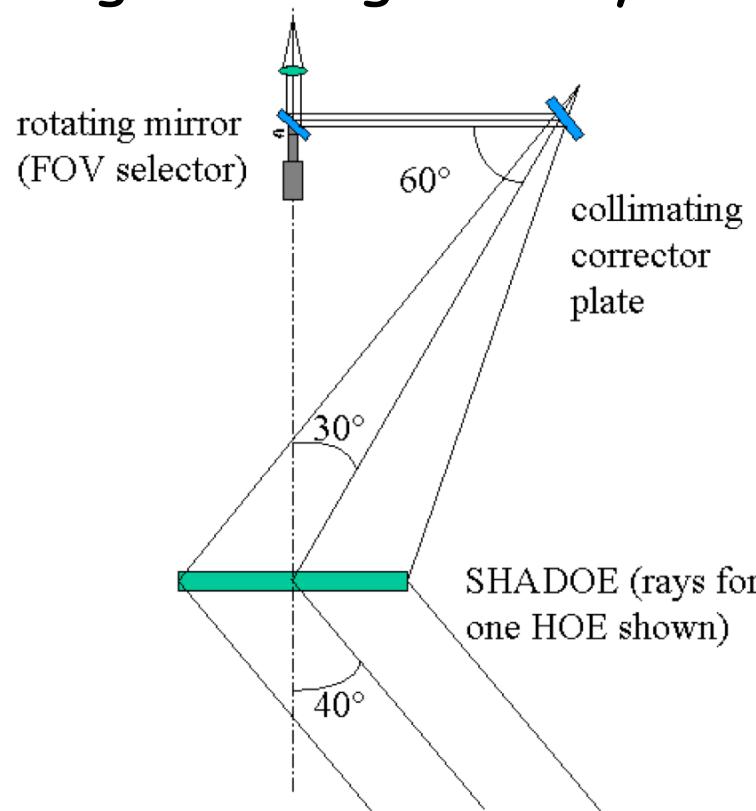
---

- Diffracts light
- Dispersive
- Limited wavelength bandwidth
- Limited angular bandwidth
- Transparent to other light
- Multiple exposures possible

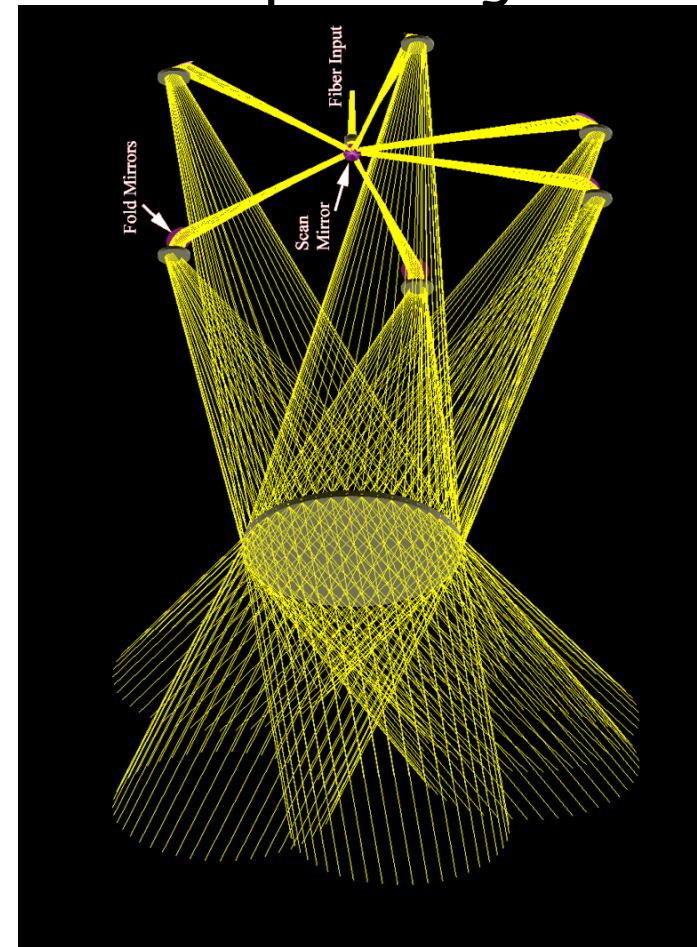


# Angle multiplexed HOEs

Single HOE geometry



6 HOE exposure geometry



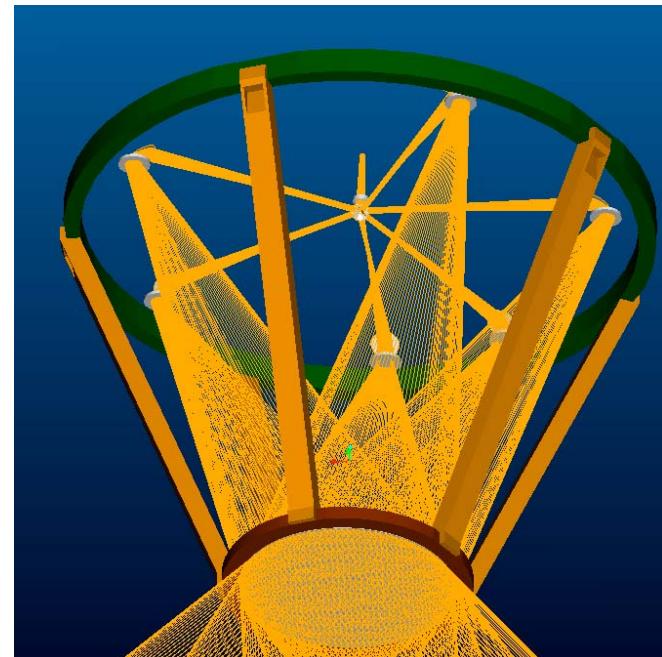


# ShADOE

---



20-cm diameter 3-hologram ShADOE for  
532nm wavelength (from SBIR).

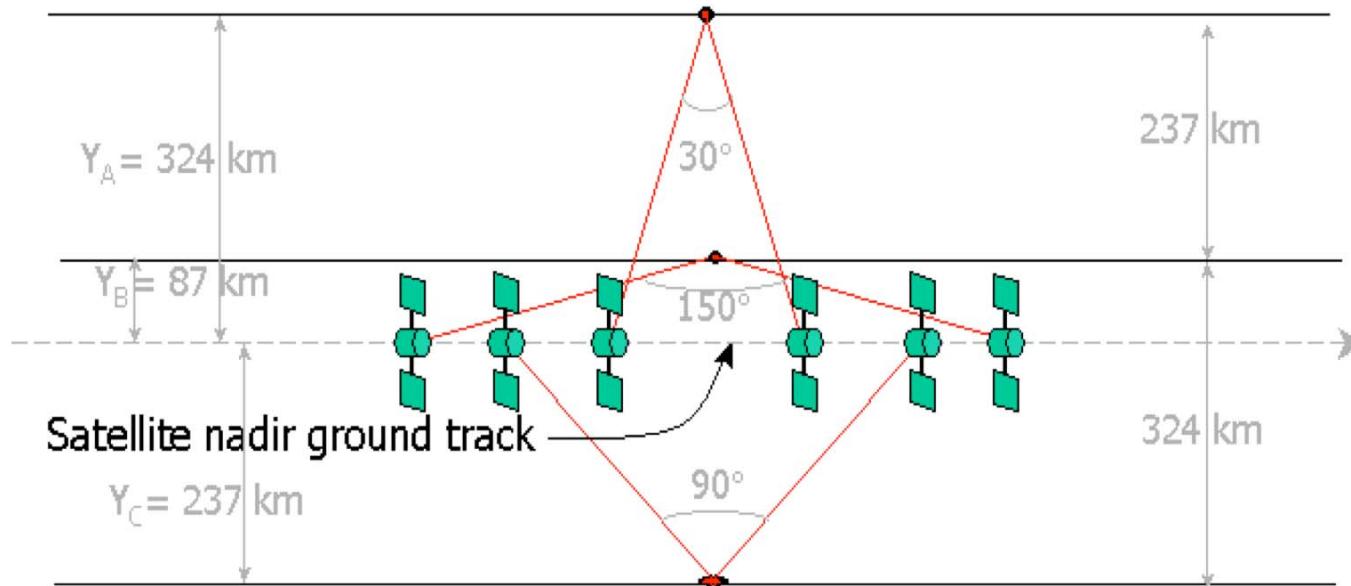


ShADOE metering structure  
concept.



# Mission Concept

6 FOVs allow 3 ground tracks with 2 perspectives each



Satellite and measurement ground tracks for a lidar orbiting at 400 km altitude and 6 lines-of-sight 40-deg off nadir. Each pair of HOEs provide two measurement perspectives into a measurement track, producing 3 tracks.





# Scanning Lidar Requirements

---

- Narrow field of view ( $200 \mu\text{rad}$ )
- Large collecting area ( $\sim 1 \text{ m}^2$ )
- Large off-nadir scan angles ( $\sim 30\text{-}50^\circ$ )
- Step-stare preferred over continuous scanning (2-16 steps)
- Rapid slew ( $< 1\text{s}$ )
- 2 ~orthogonal looks into each sample volume



# Technology Comparison

Mass and Power comparisons. (Source - GSFC Doppler Lidar Technology assessment, 2001.)

System	Total Mass	Total Avg. Power
Rotating SiC 1.25 m reflective telescope	302 kg	260 W
Scanning flat mirror	>450 kg	
Rotating Fresnel wedge	>450 kg	
Rotating 1.5-m HOE	152 kg	130 W
1.5-m ShADOE	65 kg	20 W



# 1st Year Findings

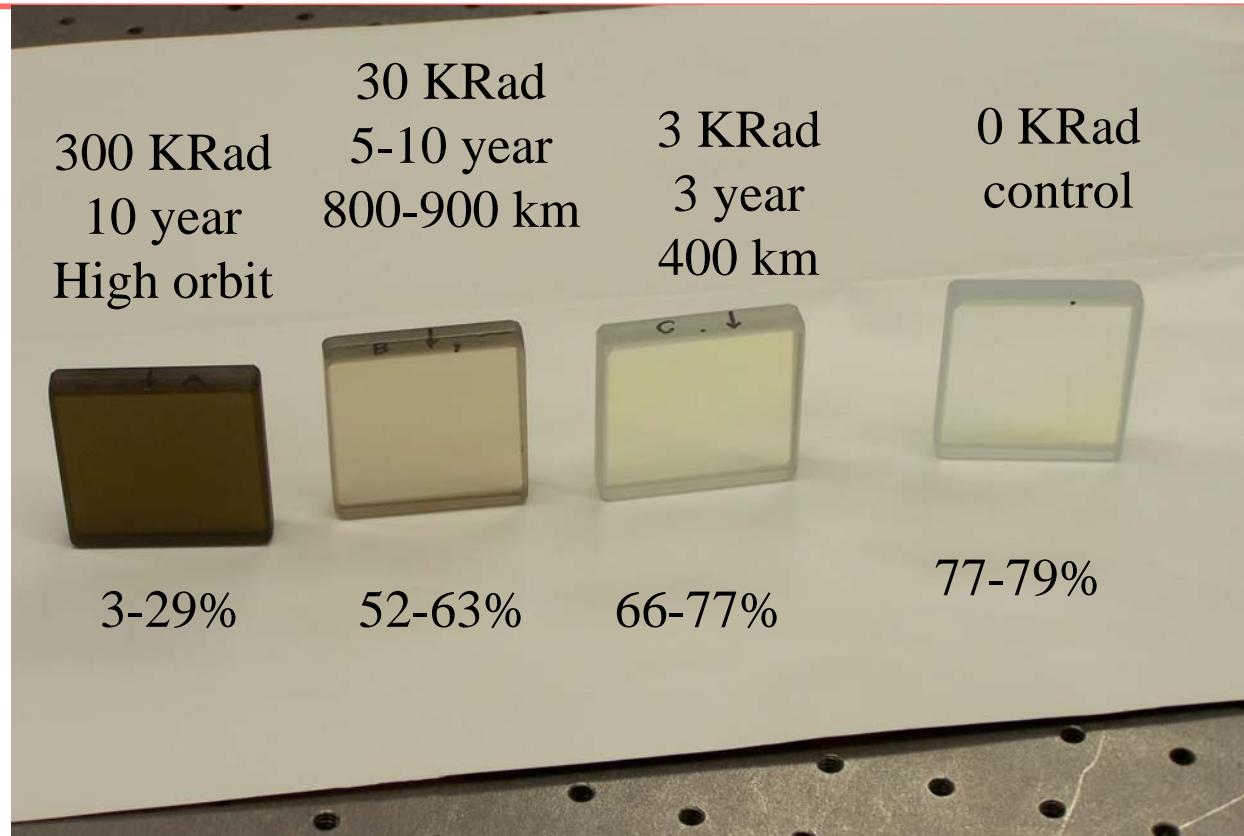
---

---

- 6 HOE exposures possible with little loss in performance
- HOE film appears unaffected by gamma and proton radiation
- Better gamma radiation resistance needed in cover glass



# Gamma Testing



Photograph of the 4 ShADoE optics involved in the gamma radiation experiment. From left to right: ShADoEs A, B, C, and an unirradiated control ShADoE. The radiation dose corresponding to various mission parameters are shown above each sample. The post-exposure, % normal transmission at 355 nm is shown below each sample, measured using 3 different techniques.



# Radiation mitigation

---

- Use suitable alternate glass
- Reduce glass thickness from 1 cm to 5 mm for NPOESS mission.



# Risk Factors

---

---

- Space environment
  - Gamma / proton / UV radiation effects
  - Vacuum
  - Other age related phenomena
- Launch vibration
- Optical performance for 2-micron wavelength HOEs



# Risk Mitigation Plans

---

---

- Identify and test new substrate glass to help mitigate gamma / electron / UV radiation effects
- Perform and test one or more wavefront correction schemes
- Purchase 2-micron diagnostic equipment (camera, laser source), work with vendors to improve production & test techniques;  
Identify alternate technologies



# Work Planned for next 6 months

---

---

- Characterize preliminary ShADOE and 2 HCPs & Finalize mounting tolerances for 355 nm breadboard system
- Complete 355 nm telescope system design
- Test final 355 nm ShADOE & HCPs
- Fabricate 6-FOV breadboard system
- Additional radiation & UV testing



# Planned Work beyond 6 months

---

- Explore greater HOE multiplexing techniques
- 2-micron ShADOE development
  - Materials qualification
  - Wavefront error correction
  - HOE efficiency/performance
- Hybrid 2-wavelength telescope system
  - Conceptual design
  - Breadboard

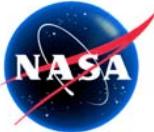


# Summary

---

---

- ShADoE weighs ~1/5 SiC mirror system
- 1/13<sup>th</sup> power requirement
- Virtually eliminates torque (~1/8000)
- Prototypes in testing
- Manageable risks



# Shared Aperture Diffractive Optical Elements (ShADOE)

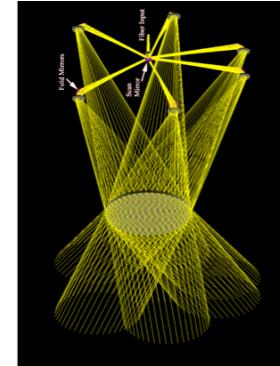
PI: Bruce Gentry at GSFC

## Objective

- Enable atmospheric Doppler (e.g. wind profiling) and surface mapping lidar applications from space
- Develop diffraction limited holographic or diffractive optical elements at 2054 nm wavelength and near diffraction limited at 355 nm
- Demonstrate a multi-wavelength shared aperture diffractive optical element (ShADOE) telescope suitable for use with single and dual-wavelength lidars



20-cm diameter 3-hologram  
ShADOE for 532nm  
wavelength (from SBIR)



6-FOV ShADOE telescope  
optical ray tracing

## Approach

- Leverage current and past investments in SBIR, GSFC R&TD and IRAD programs
- Develop and fabricate a 355 nm wavelength ShADOE telescope breadboard
- Develop and fabricate a 2054 nm wavelength ShADOE telescope breadboard
- Develop and fabricate hybrid ShADOE telescope prototype & demonstrate performance for lidar-based tropospheric wind measurements

## CoIs/Partners:

Brent Bos, GSFC; Geary Schwemmer, SESI

## Key Milestones

- |                                                                      |      |
|----------------------------------------------------------------------|------|
| • Determine 355nm beam energy and multiplexer limits of ShADOE       | 3/06 |
| • Design the 355 nm ShADOE telescope                                 | 8/06 |
| • Conduct 355 nm materials qualification                             | 1/07 |
| • Conduct 2054 nm materials qualification                            | 4/07 |
| • Develop breadboard and test 355 nm ShADOE telescope                | 7/07 |
| • Design 2-wavelength (355 nm and 2054 nm) Hybrid ShADOE telescope   | 1/08 |
| • Develop breadboard and test Hybrid ShADOE telescope $TRL_{in} = 2$ | 7/08 |



# Molecular Wind Lidar System

## Measurement Requirements

Parameter	Value	Impact to telescope
Collector area * throughput	0.45 m <sup>2</sup>	Size * efficiency
Velocity accuracy (LOS projected) (m/s)	1.5	Throughput
Nadir angle (deg)	35-50	HOE geometry, throughput
Step-stare scan pattern (1-16 FOV)	6 nominal	Throughput, crosstalk
Scan cycle time seconds (km)	112 s	FOV selector
Horizontal integration per LOS (seconds) & ground track (km)	10 s	Throughput & torque
Slew period (s)	1	FOV Selector
Field Of View	200 $\mu$ rad (355 nm) 6 $\mu$ rad (2 $\mu$ m)	Focal spot size, throughput
Pointing knowledge accuracy & precision	900 $\mu$ rad	Pointing system accuracy & calibration



# Constraints

- Volume
- Mass
- Power
- Vibration
- Torque
- Momentum compensation
- Space environment

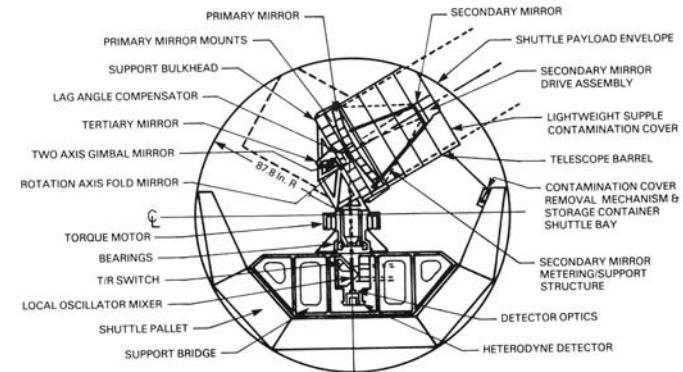


Figure 24. Side view of recommended lidar design mounted on the Space Shuttle pallet.

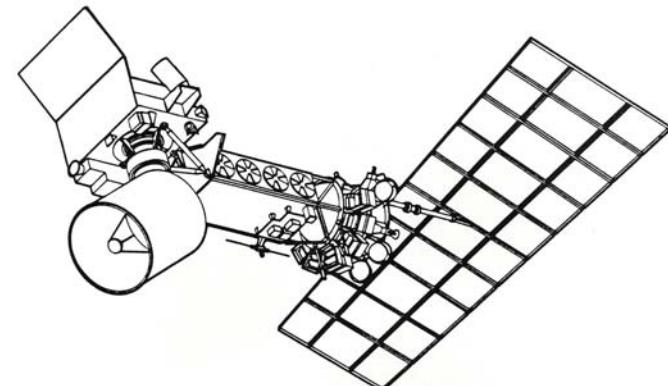


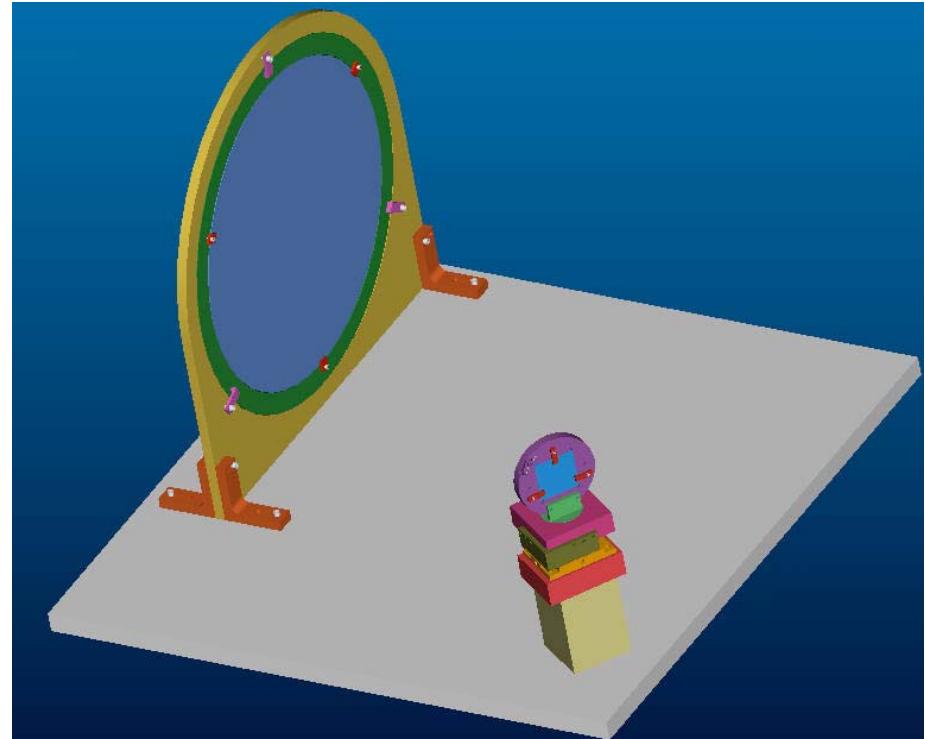
Figure 25. Windsat free flyer.



# Technical Status

---

- 16-inch 355 nm ShADOE test apparatus designed
- Preliminary alignment procedure identified





# Schedule

